EXPLORATION STRATEGIES for Ultra-Shallow Microbial Methane on the Eastern Margin of the Williston Basin

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Exploration Strategies for Ultra-Shallow Microbial Methane on the Eastern Margin of the Williston Basin

(An Extended Abstract)

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Ultra-shallow microbial methane on the eastern margin of the Williston Basin is an untested unconventional gas play. Resource potentials are indicated by favorable geologic and hydrologic conditions on the shallow basin margin and by historic gas shows. However, some exploration strategies for this potential resource are not in the tool box of strategies normally employed by the oil and gas industry.

Production from the Devonian Antrim Shale on the northern Michigan Basin margin provides exploration strategies that can be applied to organic rich Cretaceous shales on the eastern Williston Basin margin. The main exploration components can be cast in an agricultural grazing metaphor: 1) pastures of total organic carbon (TOC) for microbe grazing; 2) plumbing systems of fractures; 3) water quality that will support the microbes; and 4) multiple and sequential microbe consortia.

The TOC pasture is documented in outcrop samples (3 to 10%) and in cores. Sixty core samples from the Pierre, Niobrara, Carlile, and Greenhorn Formations at Iroquois and Sisseton, South Dakota, averaged 3.8% and ranged from .2 to 10%. TOC values vary near local paleogeographic features, such as Sioux Ridge, but regional variations conform with published trends for the Cretaceous Western Interior Seaway.

Fracture plumbing systems are available as regional corridors along reactivated Precambrian basement blocks. The fractured block boundaries are mapped as lineament zones on Landsat images and historical gas shows are clustered along the zones in the eastern Dakotas. In particular, ultra-shallow gas shows in glacial drift appear to be common over subcrops of fractured Niobrara Formation.

Water quality favorable for methanogenesis is generally high bicarbonate (greater than 400 mg/L) and low sulfate (less than 500 mg/L). A water quality data base maintained by the state of South Dakota contains more than 7200 analyses, mostly from shallow glacial aquifers. These data can be used for exploration because the microbial methane is in a hydrologic system that includes fractured Cretaceous subcrops as well as the glacial aquifers.

A geographic information system is used to sort and plot gas shows and water quality data. Clusters of favorable water quality values are found near gas shows; some clusters that have no documented gas show warrant specific investigation. Two excellent examples of water

quality clusters near gas shows are located in McCook and Charles Mix Counties, South Dakota.

The ultra-shallow Dolton Aquifer in McCook County hosts microbes that produce methane. It is also a "research farm" that provides an opportunity to demonstrate the utility of some unconventional exploration tools. Methanogens in this glacial aquifer probably use a TOC pasture in subcropping, organic rich Cretaceous bedrock. Water quality patterns conform with regional generalizations: methane occurrences are confined to an elliptical area of high bicarbonate and low sulfate ground water. Methane is documented in headspace analyses of water samples and by direct detection in the well bore above the water. Preliminary microbial experiments with water from the aquifer show active methanogenesis in wells with methane detected by field survey and headspace analyses. No methanogenesis is observed from water in wells that had no observed methane.

Exploration strategies for ultra-shallow microbial methane that are useful on the eastern margin of the Williston Basin can also be applied in other areas. For example, the Barnett Shale play in the northern Fort Worth Basin may also have a relatively unexplored microbial methane component to the south on the Lampasas Arch.

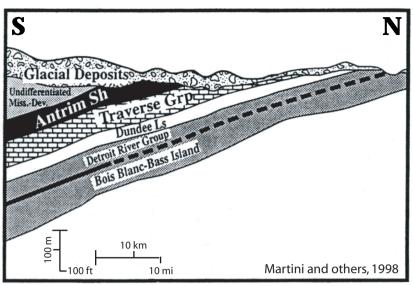


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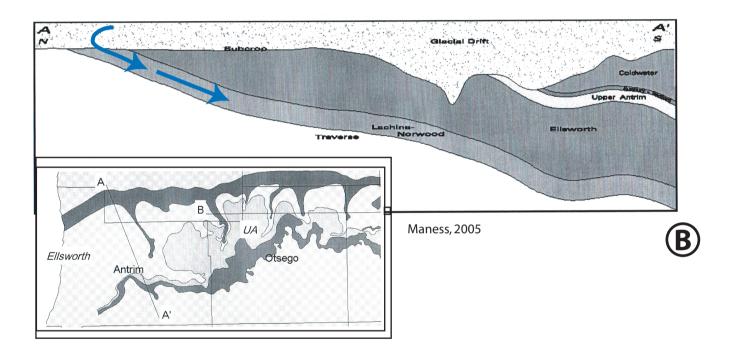
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EXPLORATION CONCEPT

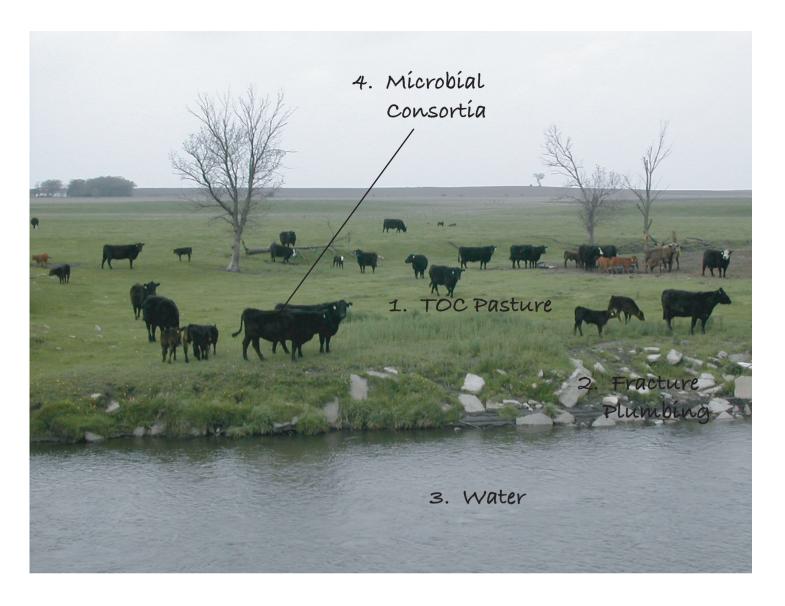






MICHIGAN BASIN ANTRIM SHALE

The Devonian Antrim Shale has produced more than 2 TCF in ultra-shallow wells ranging from 200 to 2000 ft deep. The gas is late generation biogenic gas or microbial methane that formed in the relatively recent geologic past and may continue to be generated today. Fractured, organic rich shale subcrops beneath glacial drift. At the time of glaciation, meltwater carried methanogenic microbes down dip to graze the TOC pasture and produce methane (Martini, et al., 1998).

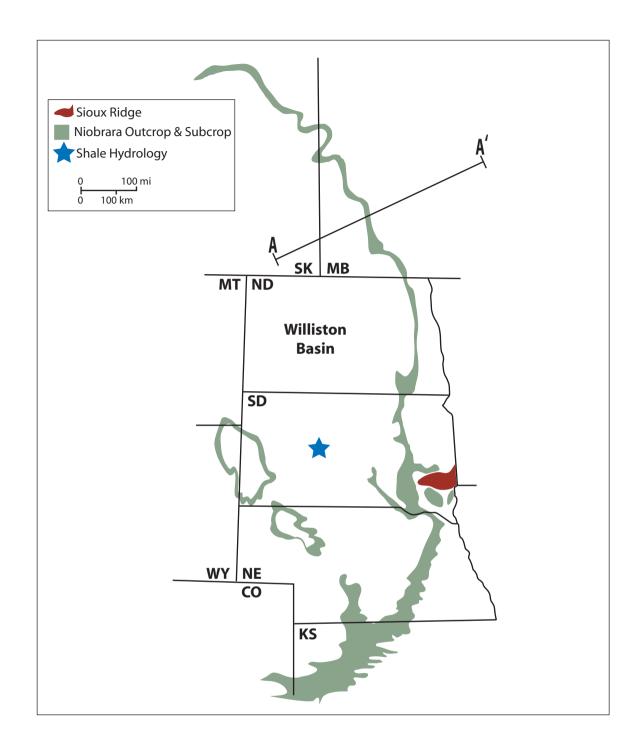


GRAZING METAPHOR

There are four main components that are important in exploration for microbial methane in the Antrim:

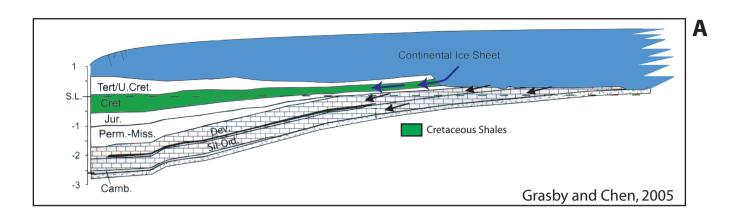
- 1. **Pastures** of total organic carbon (TOC) available for microbes to graze;
- 2. **Plumbing** system of fractures to carry water;
- 3. **Water** quality provides a favorable environment for methanogens;
- 4. **Microbial consortia** to reduce TOC to feedstocks that are subsequently used by additional microbes in methanogenesis.

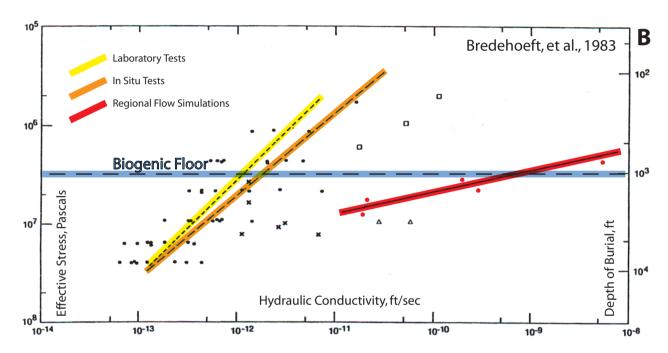
Ultra-shallow microbial methane production is basically an agribusiness endeavor.



WILLISTON BASIN CRETACEOUS "PASTURE"

The Cretaceous Niobrara Formation provides potential TOC pastures for generation of microbial methane at ultra-shallow depths. It is representative of a number of organic rich Cretaceous units that outcrop and subcrop beneath glacial drift on the eastern margin of the Williston Basin and to the north and south on the Alberta and Denver Basins, respectively.

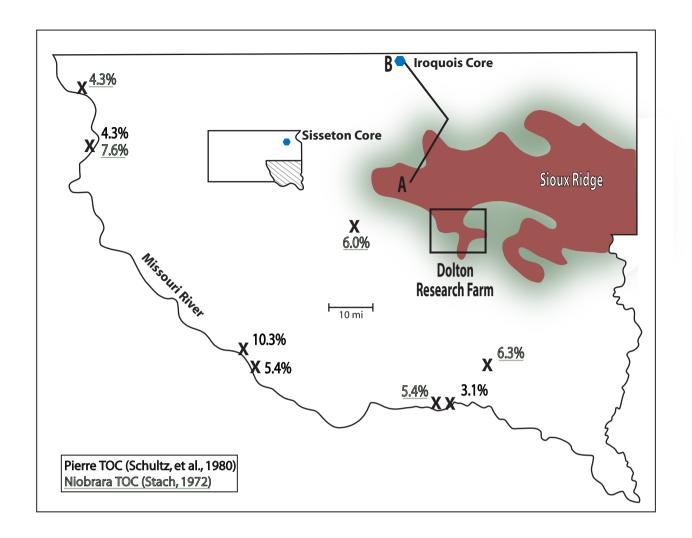




CRETACEOUS FRACTURE PLUMBING

- **A.** Cretaceous shales on the eastern Williston Basin margins had a dynamic plumbing system during and after glaciation. This cross section is part of a hydrologic study that models meltwater flow into Paleozoic units. However, fractured Cretaceous shales that subcropped beneath the glacier probably had similar hydrologic conductivities.
- **B.** Measurements of hydrologic conductivity in Cretaceous shales in central South Dakota vary with observation scale. Water circulation may be depth limited to provide a biogenic "floor". Above the floor, conditions are favorable for methanogenesis.

T 0 C PASTURES



LOCAL OUTCROP SAMPLES

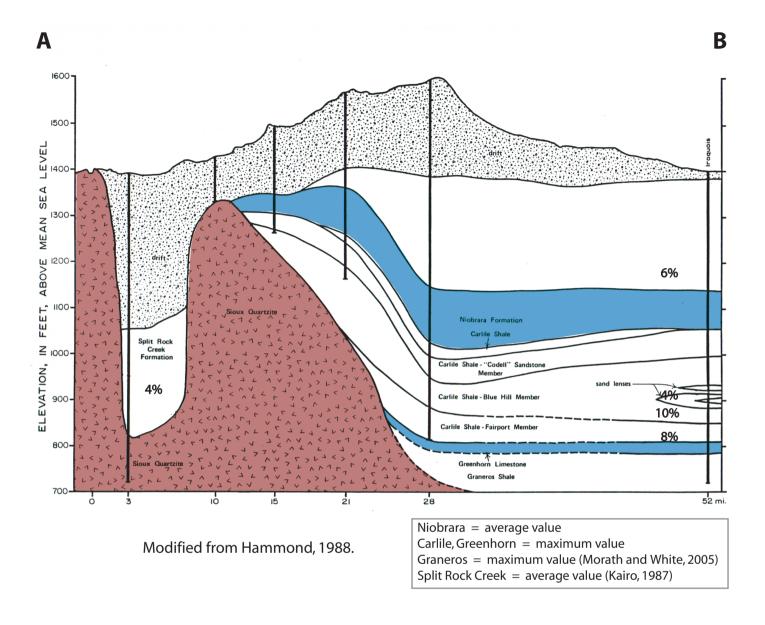
Published measurements of total organic carbon (TOC) are available for samples collected from outcrops along the Missouri River in southeastern South Dakota. Generally, only single samples of the Pierre Shale and Niobrara Formation have been analyzed. However, the TOC values are surprisingly large for outcrop samples. Subsurface samples are available from cores near Iroquois and Sisseton. The TOC pasture supports methanogenesis at the Dolton "Research Farm" on the margin of the Sioux Ridge.

TOC ANALYSES

StratigraphicUnit	Core Location	Average olo	Range ^{o o}	Number of Samples
Pierre Shale, Sharon Springs Member	Iroquois	.48	.1875	5
	Sisseton	5.54	5.17 - 6.21	3
Niobrara Formation	Iroquois	3.13	1.26 - 6.05	37
	Sisseton	2.11	1.71 - 2.87	5
Carlile Shale, Fairport Member	Iroquois	3.71	2.95 - 4.41	5
Greenhorn Formation	Iroquois	8.50	6.86 - 10.08	4
	Sisseton	6.28	3.49 - 8.05	3

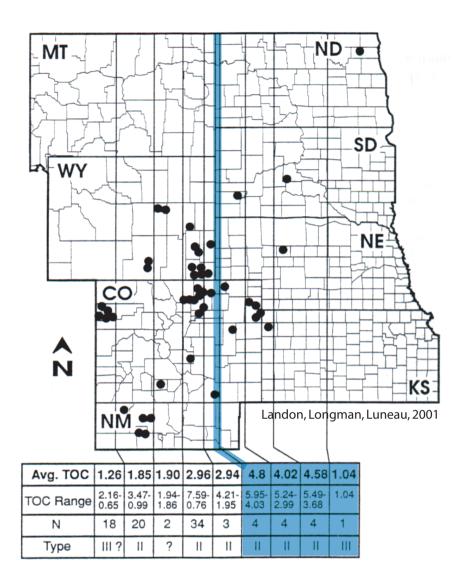
CORE TOC MEASUREMENTS

TOC measurements were made on more than 60 samples collected from four Cretaceous formations at two widely-separated core locations. TOC values range from less than .2% to more than 10%. Most of the formation averages are well above the .5% commonly recognized as the minimum for substantial microbial methane generation in modern sediments (Claypool and Kaplan, 1974). TOC pastures are available for ultra-shallow microbial methane generation on the eastern margin of the Williston Basin.



SIOUX RIDGE CROSS SECTION

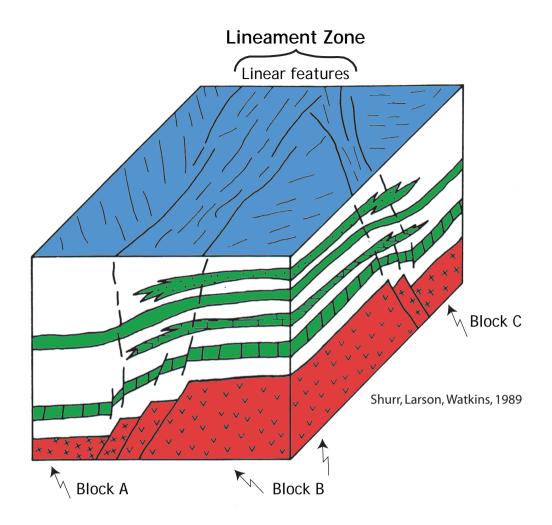
Cretaceous stratigraphic units that constitute the TOC pasture for microbes, lap up onto the Precambrian high known as Sioux Ridge. Associated facies changes may locally modify TOC content, but even the Cretaceous bedrock confined to embayments along the ridge margins have significant TOC. So the TOC pastures are available over a variety of depositional settings on the eastern Williston Basin margin.



REGIONAL TOC PATTERNS

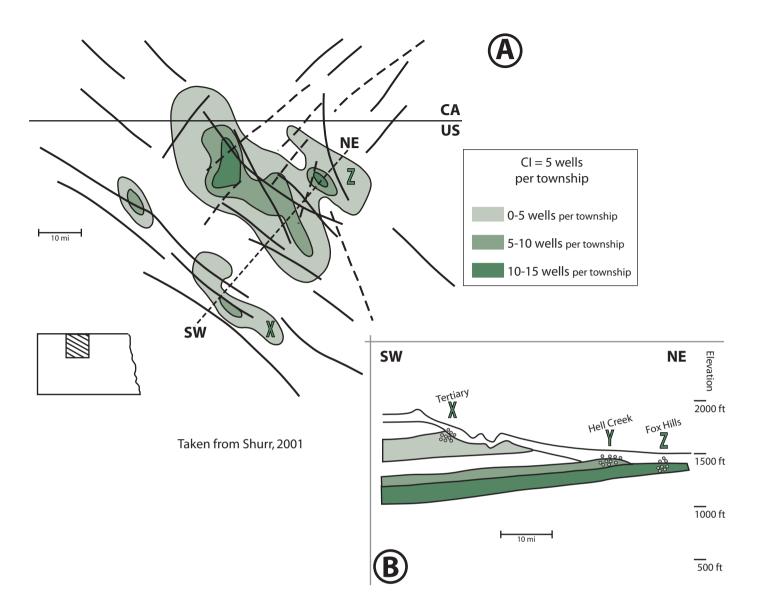
There appears to be a regional increase in Niobrara TOC values from west to east. The addition of the substantial data set in eastern South Dakota continues and supports this regional TOC pattern. Lowest values are found farthest east in the Niobrara. This is where clastic input from the low-lying eastern margin of the Western Interior Seaway exerted an influence on deposition.

FRACTURE PLUMBING



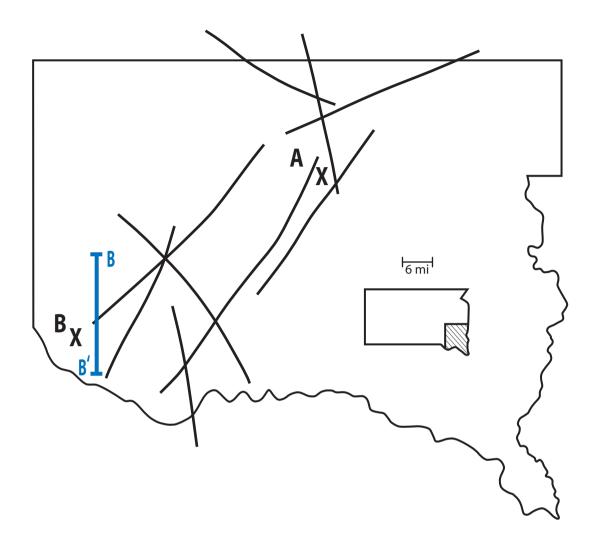
REGIONAL FRACTURE CORRIDORS

Periodic reactivation of structural blocks in the Precambrian basement produces corridors of increased fracturing in Cretaceous stratigraphic units shown in green. The corridors can be identified on the surface by mapping lineament zones on satellite images. Paleotectonism influenced Cretaceous deposition, but it is the post-Cretaceous movement that is most significant for ultra-shallow microbial methane. The fractures that result provide a dynamic plumbing system to support methanogenesis.



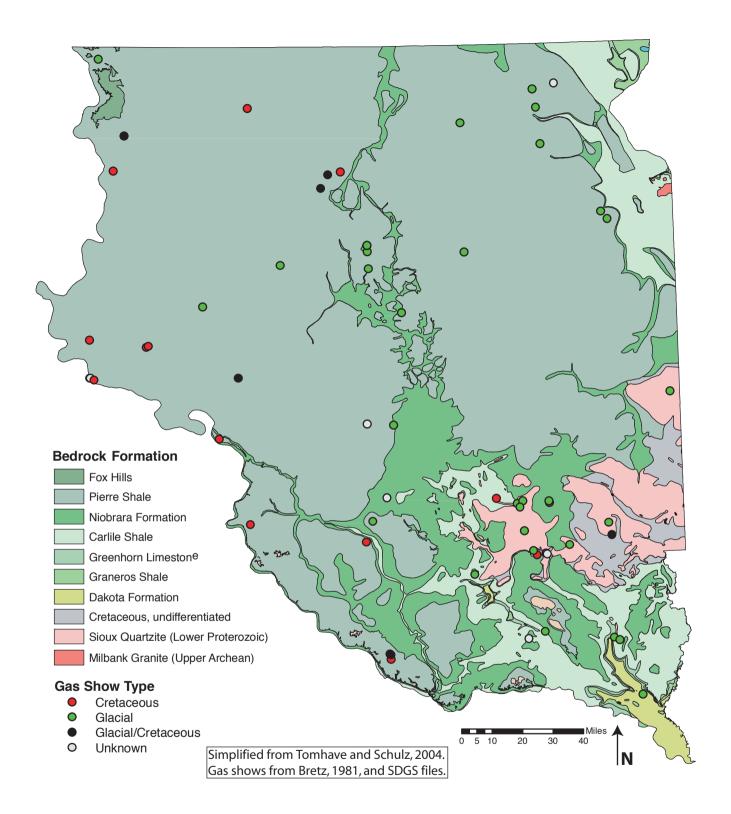
NORTH DAKOTA EXAMPLES

Ultra-shallow water wells in glacial drift commonly carry gas in this area where organic rich bedrock subcrops beneath the glacial deposits. Patterns of methane occurrences closely follow lineament trends mapped on Landsat images. The highest frequency of gas shows are found above the subcrop locations of three specific formations: Tertiary units, Cretaceous Hell Creek, and Fox Hills. At least two of these units have coal to provide TOC pastures. Correspondence of Landsat lineament zones and gas shows suggest plumbing supporting the is ultra-shallow that fracture methanogenesis. There may also be a component of gas from vertical migration.



SOUTH DAKOTA EXAMPLES

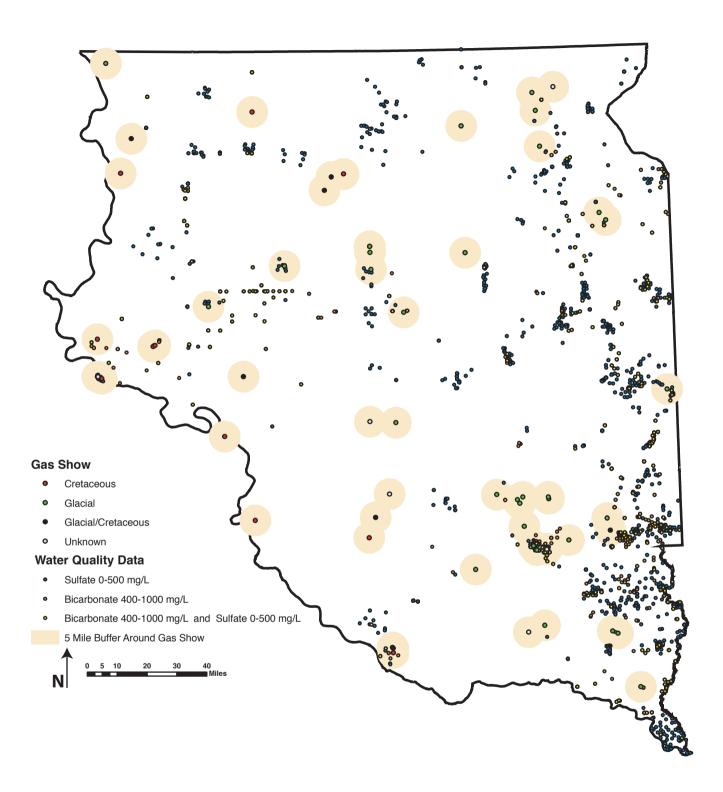
Ultra-shallow gas occurrences in southeastern South Dakota are also found with Landsat lineament zones. The Dolton "Research Farm" in McCook County is located at **A** and has numerous methane shows in a glacial aquifer lying on organic rich Cretaceous bedrock. In Charles Mix County (**B**), the Cretaceous Niobrara Formation has several gas shows. Both of these examples are described in more detail on later poster panels. And, both are consistent with the idea that a regional fracture plumbing system is available to support methanogenesis.



GAS SHOWS AND BEDROCK SUBCROP

Fractured Niobrara Formation probably influences the distribution of gas shows in glacial drift in eastern South Dakota. Many drift gas occurrences are located on or near the Niobrara subcrop.

REGIONAL WATER & GAS



GAS & WATER CONTINUED

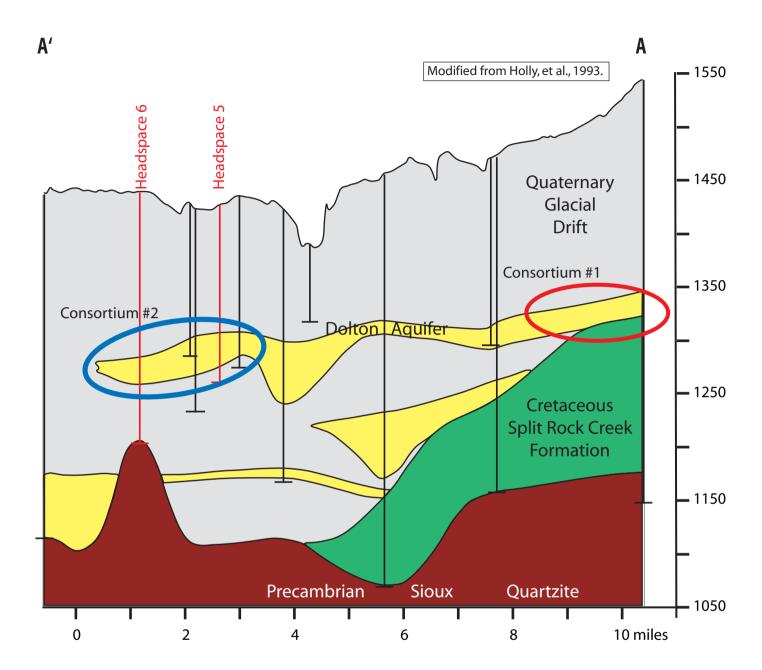
CLUSTER TYPES



- I. Multiple gas shows and multiple or single water quality locations. N = 10.
- II. Single gas show and multiple or single water quality locations. N = 8.
- •
- III. Single gas show and no water quality locations. N = 18.
- IV. No gas show and multiple water quality locations. N > 30.

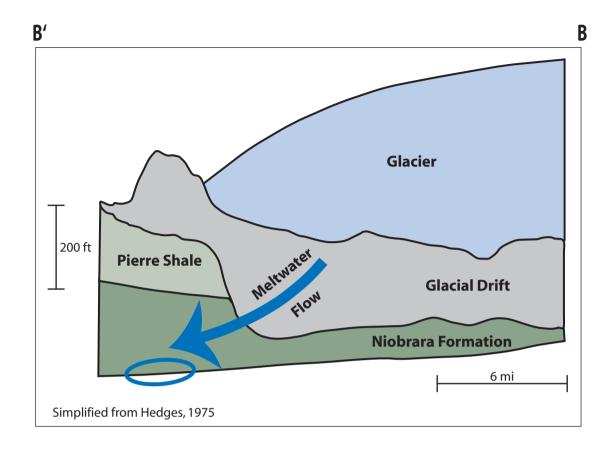
NUMBER OF WATER ANALYSES

7232	Total SDGS data base, September, 2005.
3978	Sulfate values less than 500 mg/L
1076	Bicarbonate values 400 to 1000 mg/L.
732	Sulfate < 500 mg/L and Bicarbonate 400 - 1000 mg/L



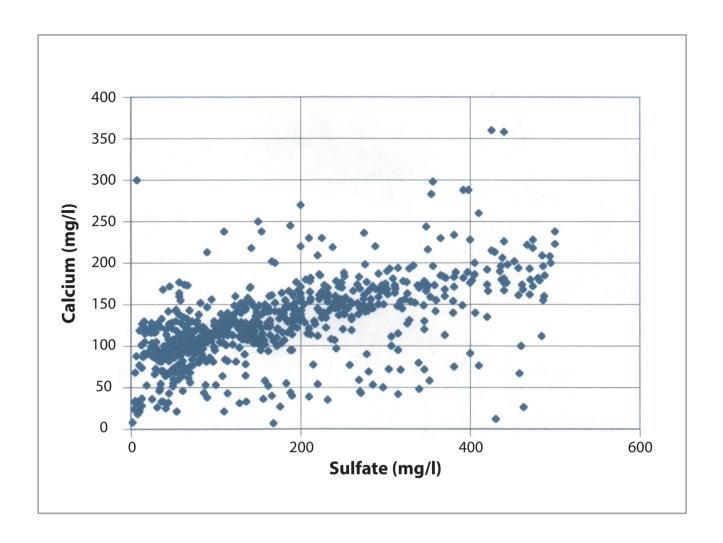
DOLTON "RESEARCH FARM"

A large number of ultra-shallow water wells in southern McCook County, South Dakota, provide an opportunity for field-scale investigation of microbial methane. The "research farm" includes at least two microbial consortia. Consortium #1 grazes the TOC pasture in Cretaceous bedrock and produces a feedstock (probably acetate) that is transferred by ground water flow to the area of methanogenesis. Consortium #2 utilizes the acetate feedstock to make methane 6 to 10 miles from the TOC pasture.



CHARLES MIX COUNTY, SOUTH DAKOTA

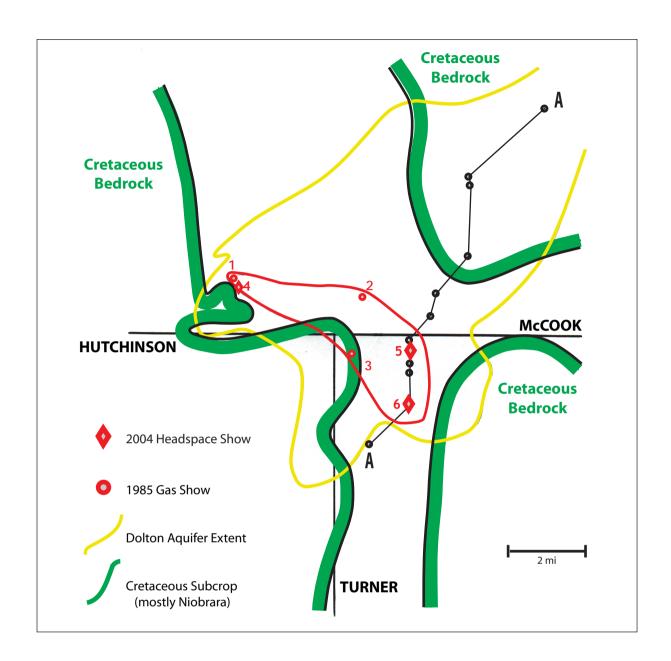
This cartoon cross section suggests the probable origin for ultra-shallow gas shows in the Niobrara Formation (Bretz, 1981) located near a glacial margin. Fractured Niobrara provided the TOC pasture for microbes that are carried by meltwater flow. Modern subglacier meltwater has been demonstrated to contain active microbial populations that might be able to ferment organic carbon (Sharp, et al., 1999). Thicknesses of drift sediments were probably much smaller when the glacier was present.



REGIONAL WATER QUALITY

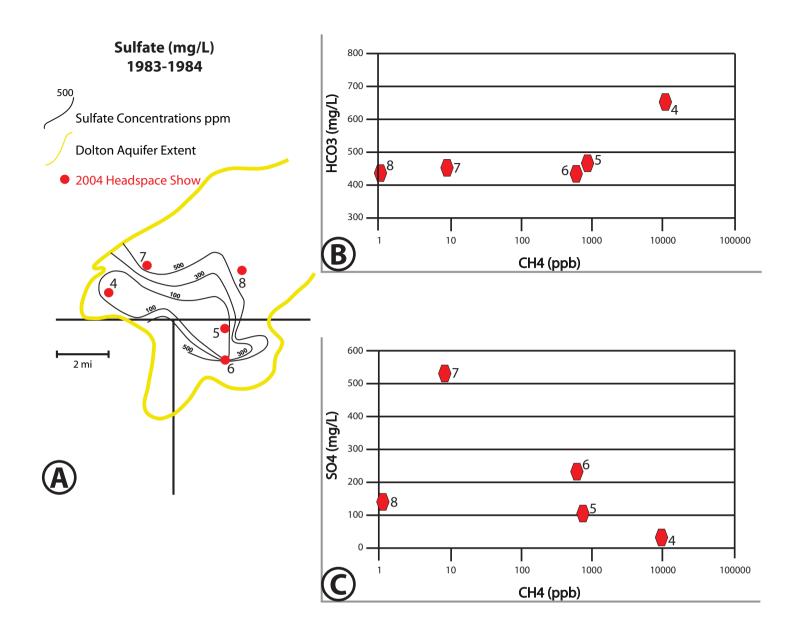
Low sulfate and high bicarbonate values are associated with shallow gas production (Walter, et al., 1997; Van Voast, 2003). In addition, calcium and magnesium show systematic patterns with gas production (McIntosh, et al., 2004). This cross plot utilizes the regional data set with sulfate values less than 500 mg/L and bicarbonate values of 400 to 1000 mg/L. Although calculations of Ca/Mg molar ratios do not conform with published trends, low calcium values do correspond with methane occurrences in the Dolton Aquifer.

DOLTON GAS & WATER



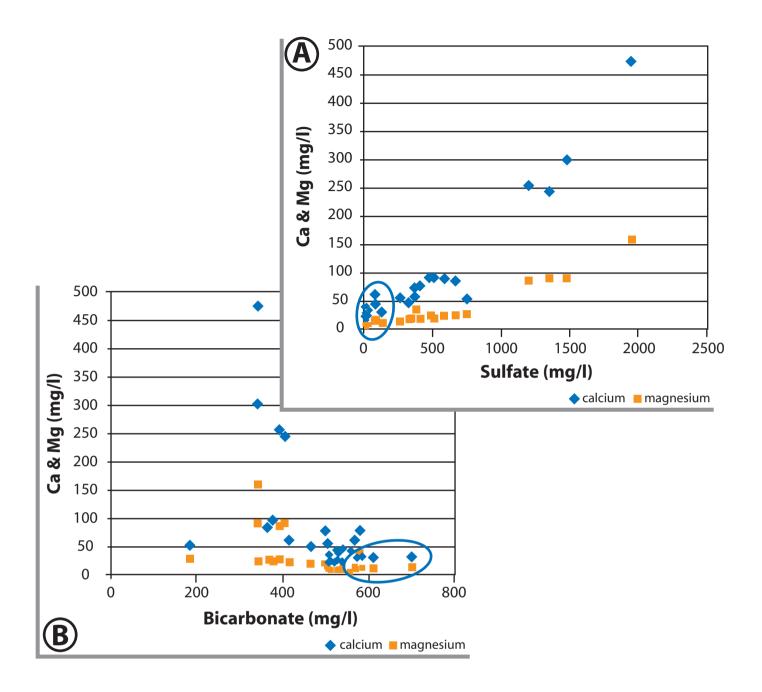
DOLTON AREA MAP

The Dolton Aquifer is an elongate glacial outwash body that overlies, but is not confined to, a deep channel cut into Precambrian quartzite. Cretaceous bedrock with high TOC is preserved along the sides of this channel and subcrops beneath glacial drift. Gas shows include historical anecdotes (1-3) and headspace measurements (4-6). The red outline is interpreted to be the area of active methanogenesis, but the TOC pasture is up-dip at location **A**.



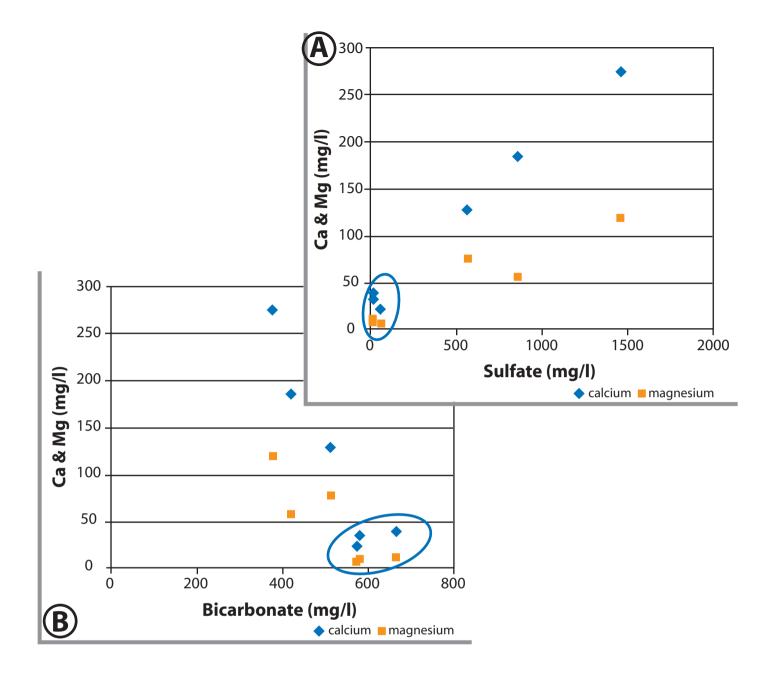
HEADSPACE MEASUREMENTS

Five samples collected for headspace measurements demonstrate that high values of methane are associated with low sulfate and high bicarbonate values. This confirms the relationship shown by contours (A) of water quality (Holly, et al, 1993) and anecdotal shows. Specifically, the highest methane values (4, 5, & 6) show a direct relationship with bicarbonate (B) and an indirect relationship with sulfate (C). The lowest methane values (7 & 8) are located outside the low sulfate area (A) and do not generally follow the bicarbonate (B) and sulfate (C) relationships.



PRE-2000 WATER CHEMISTRY

Water quality studies done as a part of hydrologic investigations of the Dolton Aquifer (Holly, et al., 1993) show relationships similar to those in the regional data set. Calcium and magnesium vary directly with sulfate (A). In addition, calcium and magnesium vary inversely with bicarbonate (B). The headspace measurements link low calcium and magnesium concentrations with higher values of methane (blue ellipses on A & B).



WATER CHEMISTRY AND HEADSPACE VALUES

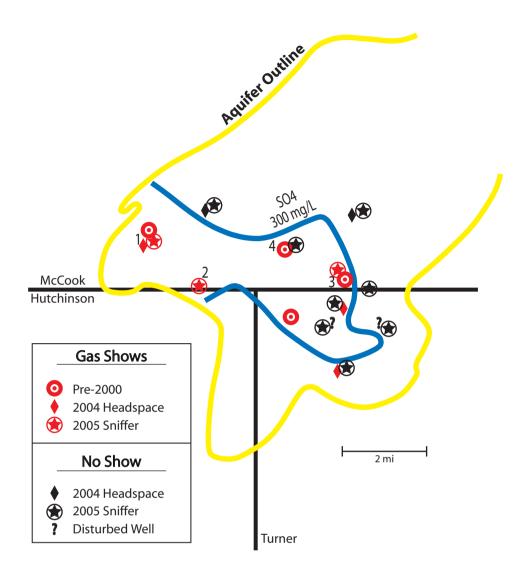
Water samples taken for headspace measurement were also analyzed for water chemistry. The three highest methane values are in water with low Ca and Mg and low sulfate (A) and high bicarbonate (B). However, calculations of Ca/Mg molar ratios do not show lower values for the samples with high methane. So, the Dolton water chemistry and methane measurements do not follow patterns observed in the Antrim (McIntosh, et al., 2004)

DOLTON GAS & MICROBES



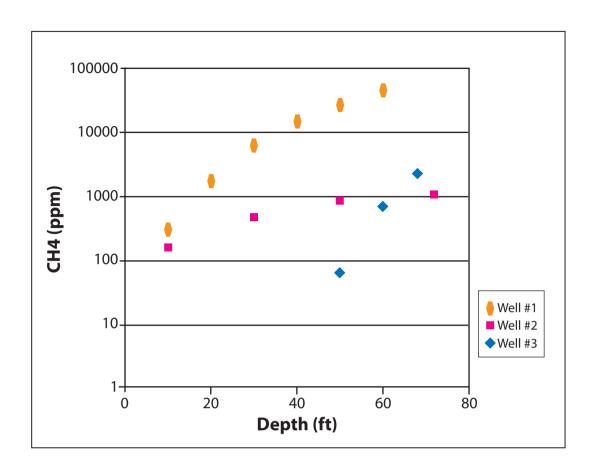
DIRECT GAS DETECTION ("SNIFFER")

Direct detection of gas in observation wells is a common technique employed in environmental studies. The technology was employed in the ultra-shallow Dolton Aquifer in 2005. A long sampling hose was lowered down the well bore and observations were made at progressively deeper locations. The maximum observation depth in all wells is 10 ft above the water level. Values of methane, CO2, and O2 were recorded at each measurement depth. The gas detection meter is an example of a tool routinely used in environmental work that has useful application in exploration for ultra-shallow gas.



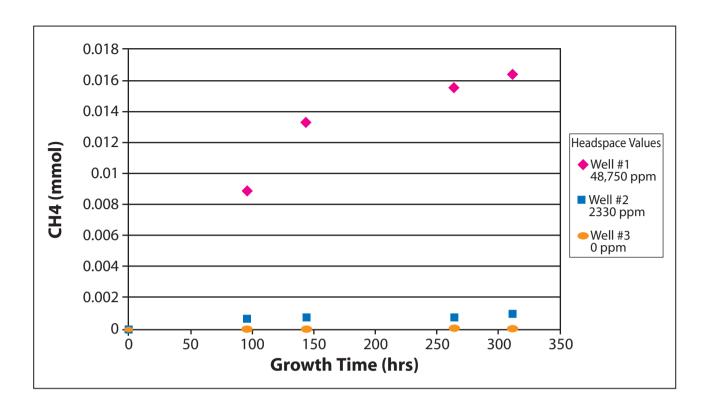
SNIFFER SUMMARY

The gas detection survey was conducted in eleven wells. Three wells (*red stars*) had elevated methane and are located within the postulated methanogenesis area. Five wells shown by black stars outside the optimal water chemistry area had no methane as expected. Three wells shown by black stars within the area did not have the anticipated methane shows. Two are near the margins of the methane area and one was disturbed by a prior water level survey. *Wells 1, 2, & 3* show characteristic profiles of methane increasing with depth.



SNIFFER PROFILES

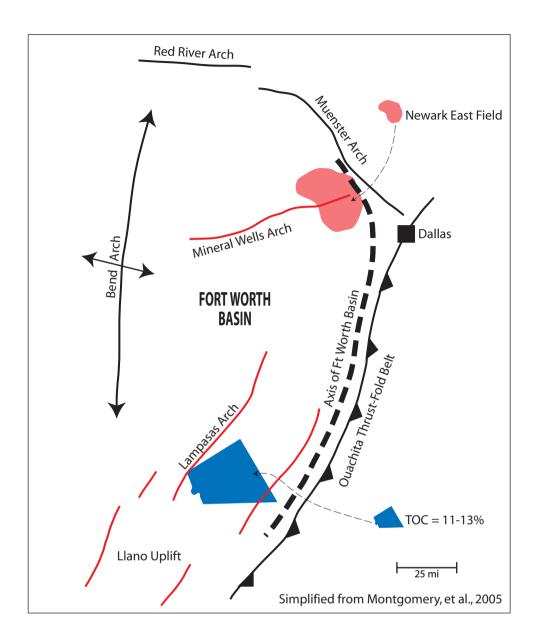
Methane values increase with depth, although vertical variation is not the same in all three wells. Note that the CH4 axis is logarithmic, so the linear slopes are characterizing exponential increases. **Well #1** has the highest observed values and also is the location of the highest headspace measurement. **Well #2** has favorable water chemistry, but no headspace measurement to compare with the sniffer survey. **Well #3** is a new show well discovered during the sniffer survey without benefit of previous water chemistry or headspace data.



PRELIMINARY MICROBIAL EXPERIMENTS

Water samples from three wells with distinctively different headspace methane values were sampled for experiments to test for methanogenic activity. Experimental tubes containing Tanner media, sodium acetate, and H2 and CO2 gas were inoculated with water samples. Gas samples were removed periodically over a period of more than 300 hours and analyzed with a gas chromatograph. Active methanogenesis is documented for *Well #1* which has the highest headspace methane. *Well #2* with lower headspace values had less conclusive indication of methanogenesis. And *Well #3* had no methanogenesis. These experiments were carried out at the South Dakota School of Mines and Technology by graduate student Michael Green under the supervision of Dr. Patrick Gilcrease.

CONCLUSION AND REFERENCES CITED



WHO CARES?

Ultra-shallow accumulations of microbial methane are generally unassessed as potential gas resources. Consequently, they represent a unique exploration opportunity--even in relatively mature basins. For example, the Barnett Shale ply is currently "hot" in the deep Fort Worth Basin. But, it is thermogenic gas. Immature, high TOC shales in Lampasas County are located near faults on the southern basin margin. Microbial methane might be present in these pastures of fractured shale (and leases may be a lot less expensive?)

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